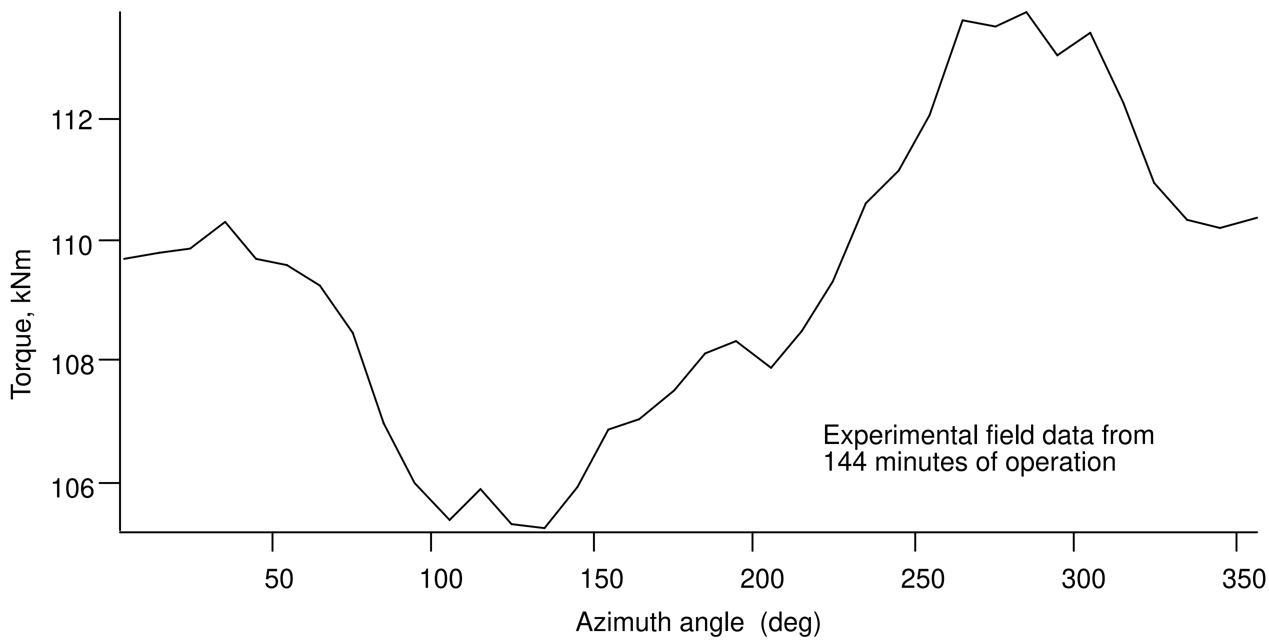

Figure B.1 - Typical periodic variation in shaft torque

This may be especially important in designing gearbox components that do not change position with respect to the rotor over time (for example the low speed gear). It may also be important in selecting the number of teeth on the intermediate and high speed shafts. The number of teeth should be selected so the same pinion and gear teeth are not always engaged at the maximum torque position of the rotor. This can be achieved by using hunting tooth combinations.

B.5.2.1.4 Maximum operating loads

The maximum operating load is the highest load in the load spectrum.

Over its design life, a wind turbine may experience many high load cycles during normal operation that cannot be witnessed by either experiment or analysis due to their infrequency. These events may be due to extreme wind speeds or rare three dimensional turbulent flow conditions. These load events may contribute significantly to the fatigue life of the wind turbine and gearbox, and their effects must be included when developing the fatigue load spectrum.

Several analytical techniques are available to calculate these loads using a limited amount of data. Typical methods involve extrapolating the extreme values from the tail of the measured or calculated torque load distributions. Extrapolation techniques are discussed in references [14], [15], [16] and [17]. None of these methods have been fully validated, but they provide a framework for addressing the problem.

B.5.2.2 Transient loads

In many cases, the peak transient loads can be significantly greater than the extreme loads experienced during normal operation. Although they comprise only a small fraction of the operating time, they can significantly affect the service life of the gearbox and other components on the wind turbine. Moreover, understanding and controlling these transient loads is a sensible way to extend the life of a wind turbine without affecting its cost or productivity. Table B.1 gives many of the transient wind turbine design conditions that should be considered in developing the torque load spectrum.

B.5.2.2.1 Braking event description

In gearboxes with brakes on the high speed shaft, HSS, the gear teeth, bearings and other components may be subjected to very high transient loads during stopping that significantly exceed the design operating loads. These loads must be included in the load spectrum.

Figure B.2 shows a typical record of rotor shaft torque during a HSS brake stop. This wind turbine has a fixed pitch hub and blades equipped with pitching tips that act as aerodynamic brakes during stopping. At point 1 the generator is producing power. At point 2 the blade tips deploy dragging the generator into negative power. Between points 2 and 4 the drive train oscillates at its torsional natural frequency through one or more backlash/load reversal cycles. The mechanical brake is being applied but is not yet fully engaged. At point 3 the torque rises rapidly as the brake engages and the rotational velocity decreases. At point 4 the HSS comes to a stop. The shafts torsionally wind and unwind as the gear teeth are loaded on both their front and back sides through many backlash cycles, shown at point 5. These rapid torque reversals are repeated many times while the transient vibrations decay. In addition to causing gear tooth impact, torque reversals on helical gears cause reversing thrust loads and impact loads on the gearbox bearings and housing. Gear tooth backlash and bearing endplay should be minimized to limit stress caused by such impacts.

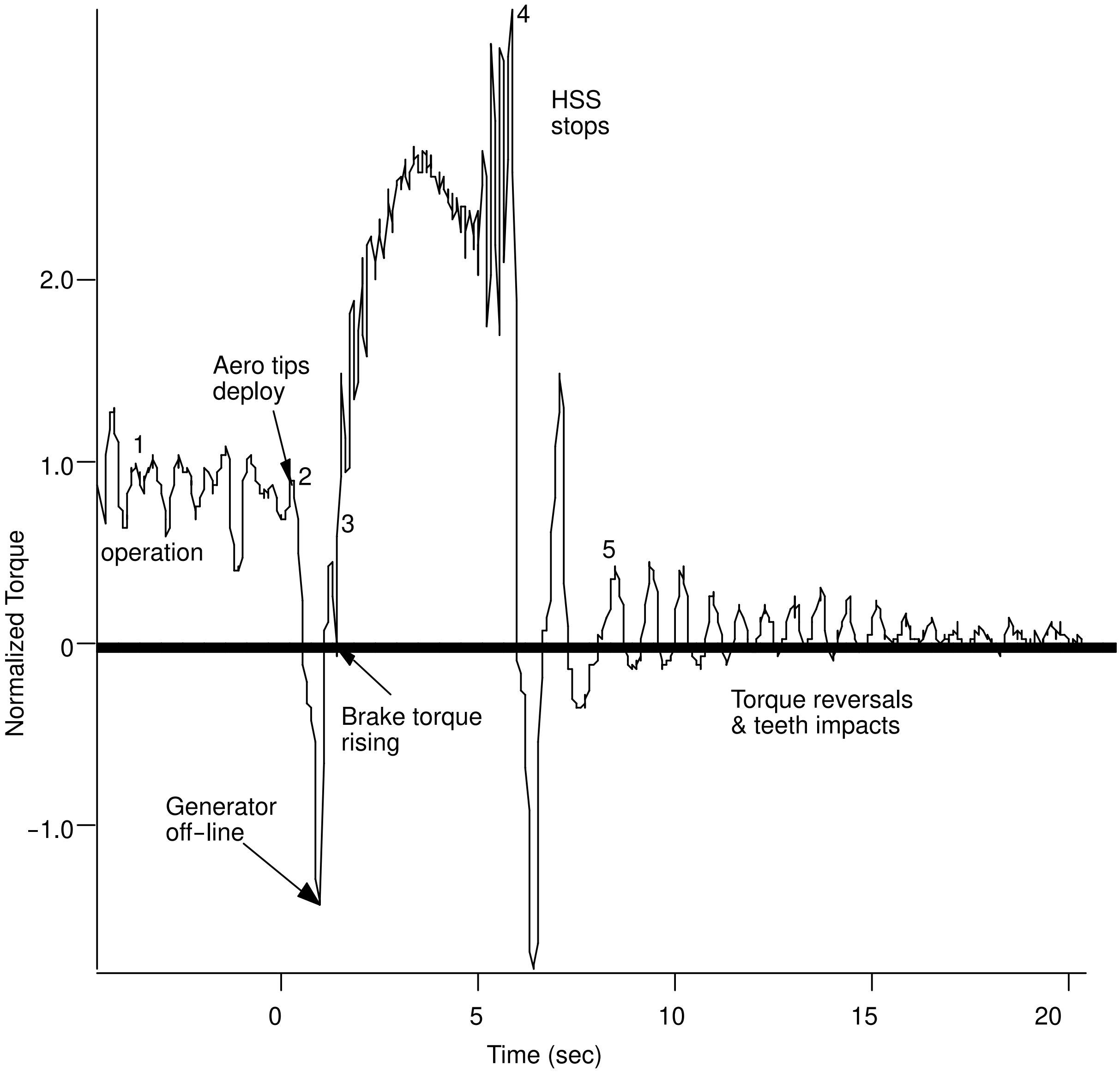

Figure B.2 - Rotor shaft torque during braking event

B.5.2.2.2 Transient event spectra

Each transient event such as tip deployments, rapid pitch events, startup synchronization, shifting between multiple generators, has a unique signature, similar to figure B.2, which should be characterized first in the time domain by the wind turbine designer. These data are then analyzed in a similar way to the method described above for operating loads; by placing measured data or analyzed data into load spectra bins. Extreme caution should be used in taking data from other wind turbines to represent transient events because small changes in the configuration, components, or control strategy can make large differences in the dynamic response of the drive train. A dynamic simulation model of the drive train, which accounts for the rotating inertia and material stiffness of each component, should be used to generate the torque spectrum for the single event. One such model is described in references [18] and [19].

For each transient event type the wind turbine designer should estimate the number of probable occurrences over the life time of the wind turbine and scale the single event load spectrum by this quantity. These numbers should take into account the external effects such as the reliability of the grid. In some cases, a time series description of a typical event should be provided to the gearbox manufacturer to help describe the nature of the loading.

B.5.2.3 Combining torque load spectra

The normal operating load spectrum should be combined with the spectra for each of the transient conditions contributing to the torque load spectrum. This should be done by simply adding the contributions of each spectrum together, bin by bin. Depending on the uncertainty in the data, it may be necessary to apply some margin of safety to the loads. Such multipliers may be different for each design load case, and they may be required by IEC or other standards. The final spectrum and load descriptions should be submitted to the gearbox manufacturer with the other turbine information listed in annex E.

B.5.3 Extreme load

The extreme load is that load from any source, either operating or non-operating, that is the largest single load that the gearbox will see during its design life beyond which the gearbox no longer satisfies the design requirements. This load can be either forces, moments, torques, or a combination of the three. This load, supplied by the wind turbine manufacturer, includes all partial load safety factors.

Most wind turbines are designed to withstand a single extreme load event using ultimate strength criteria. This event is described by the IEC-61400-1 wind turbine safety standard, and it is based on a maximum load occurrence. The extreme design load will dictate the strength of many wind turbine components. This design condition is usually calculated with the rotor stopped and the blades oriented flat to the wind. Therefore, most of the load acts perpendicular to the rotor plane. This condition may not impart high or excessive torque loads to the system, but its influence should be considered.

The maximum one-time load event for a gearbox is likely to be a consequence of other events such as an emergency brake stop, generator short circuit fault or utility grid event. The wind turbine designer should determine the likely magnitude and probability of this maximum load and specify it separately to the gearbox designer. Other extreme load cases may apply to various gearbox components, for example bearings or housing, and they should similarly be specified and described.

B.6 Other loading

For integrated gearbox systems it is necessary to specify the load spectrum at all of the critical housing interfaces. An integrated gearbox housing supports the rotor bearings, and it commonly contains interfaces for the generator, pitch mechanism and yaw system. All of these subsystems transmit loads through the housing. Therefore a thorough analysis is required to describe all interface forces and moments.

Low speed shaft loads should include the lateral loading and bending moments resulting from such items as rotor weight, gyroscopic yaw loads, unsteady aerodynamics, wind shear and rotor thrust. The gear housing and housing base should be designed to withstand overturning moments and shear loads due to rotor thrust, as well as the torsional moments reacted through the gearbox and generator. A complete fatigue load spectrum should be developed for each of these interfaces, but the procedure for doing this is beyond the scope of this annex. The proper development of these loads requires a detailed dynamics simulation model [20], [21], [22] and [23] or a rigorous test program.

(This page is intentionally blank)

Annex C
(informative)
Quality assurance

[The foreword, footnotes and annexes, if any, are provided for informational purposes only and should not be construed as a part of ANSI/AGMA/AWEA 6006-A03, *Standard for Design and Specification of Gearboxes for Wind Turbines.*]

C. Purpose

This annex explains the procurement process required to obtain reliable wind turbine gearboxes. It describes the procurement specification, quality assurance plan, quality control tests, quality documentation, and explains responsibilities of purchasers and gearbox manufacturers.

C.1 Definitions

Procurement specification - Specification designed and maintained by the purchaser that defines the application and load spectrum, and specifies minimum requirements for design, manufacturing, quality assurance, testing, and gearbox performance.

Design audit - Systematic and independent examination of engineering drawings and specifications to determine if all components of a gearbox meet requirements of the procurement specification.

Independent examination - Audit performed by a third party auditor or by a purchaser representative. As an alternative to an independent examination, the purchaser and gearbox manufacturer may agree to an appropriately documented internal audit performed by the gearbox manufacturer.

Quality assurance, QA, plan - Manufacturing specification designed and maintained by the gearbox manufacturer that specifies QA inspections, tests, and acceptance criteria for monitoring and controlling the manufacturing process.

Quality audit - Systematic and independent examination of a manufacturer's facilities to determine if equipment and quality procedures comply with requirements of the QA plan, and if QA inspections and tests are implemented effectively and meet requirements of the procurement specification.

Test audit - Systematic and independent examination of the QA plan and witnessing of tests to determine if tests of prototype, first article, and production gearboxes meet requirements of the procurement specification.

Manufacturing schedule - Schedule specifying start and finish dates for significant steps in the manufacturing process, including hold and witness points, for inspection and tests.

Manufacturing audit - Systematic and independent examination to determine if manufacturing, inspection, and testing of manufactured components comply with requirements of the QA plan, and if the components meet requirements of the engineering specifications and the procurement specification.

Prototype gearbox - The first gearbox of new design that is load tested in the field or on a test stand. After testing, the gearbox is completely disassembled and all components are inspected for wear or other distress. Based on the results of the prototype test, changes to design or manufacturing may be necessary. See 4.8.1 for further information.

First article gearboxes - One or more gearboxes manufactured before the start of manufacturing of a production lot of gearboxes. Components for first article gearboxes are 100% inspected for conformance to engineering specifications and requirements of the procurement specification, to ensure manufacturing and the QA plan are adequate. Based on the inspections of first article gearboxes, changes to manufacturing or the QA plan may be necessary. Requirements for run-in and load tests should be negotiated between the purchaser and gearbox manufacturer.

Production gearboxes - Gearboxes manufactured in production lots. Periodic manufacturing audits are conducted to ensure compliance with all specifications. Requirements for run-in and load tests should be negotiated between the purchaser and gearbox manufacturer.

C.2 Responsibilities

The procurement process involves many steps that evolve over time. Therefore, the purchaser should have resources adequate to ensure that each step of the procurement process is properly implemented and all requirements of the procurement specification are met. The purchaser is responsible for:

- procurement plan;
- procurement specification;
- bidding instructions;
- purchase order;
- design audit;
- QA plan audit;
- manufacturing schedule audit;
- manufacturing audit;
- test audit;
- installation, startup, and operation audits.

The gearbox manufacturer should have proven experience and capability necessary to manufacture gearboxes that conform to the procurement specification. The quality management system should provide resources adequate to ensure that each step of the design process, verification activities including testing, and manufacturing process is properly implemented and all requirements of the QA plan are met. The gearbox manufacturer is responsible for:

- proposal data;
- contract data;
- engineering drawings and specifications;
- QA plan;
- manufacturing schedule;
- pricing;
- warranty;
- instruction manuals.

C.3 Procurement plan

The following plan guides the purchaser through all phases of the procurement process from writing the procurement specification to auditing gearbox start-up.

C.3.1 Write procurement specification

A comprehensive procurement specification should be written to ensure a reliable gearbox. The procurement specification should define performance rather than design and should allow the gear manufacturer creative freedom to meet contract requirements by applying their engineering expertise. See the main body of ANSI/AGMA/AWEA 6006-A03 for guidelines for content of the procurement specification.

C.3.2 Solicit bids

The purchaser should solicit bids from gearbox manufacturers who have the experience and capabilities necessary to produce gearboxes that conform to the requirements of the procurement specification. Bid solicitation should include a questionnaire that determines if the gearbox manufacturer understands the procurement specification and has experience and capabilities to produce reliable gearboxes. A formal audit of the questionnaire response including a reference check and capability study is recommended for each major procurement. Bid solicitation should require a preliminary QA plan such as shown in table C.1.

C.3.3 Evaluate proposals and select final bidders

The purchaser should evaluate the gearbox manufacturer's proposals for completeness and conformance to the requirements of the procurement specification. Proposals should be compared and the best proposals should be selected for design review meetings. To determine manufacturer's capabilities, quality audits may be necessary.

C.3.4 Meet for design review meetings

Design review meetings should be conducted with final bidders and evaluations of each proposal should be written. Evaluations should discuss the relative merits of each proposal and provide sufficient information to select a gearbox manufacturer and perform a design audit.

C.3.5 Select gearbox manufacturer, audit design, and award contract

After considering the relative merits of each proposal, the purchaser should select the final gearbox manufacturer and audit the gearbox manufacturer's proposal. The design audit should include the following as a minimum:

- conformance to procurement specification;
- gearbox design;
- gear design;
- bearing design;
- shaft design;
- seal design;
- lubrication system design;
- QA plan for critical components.

Table C.1- Sample QA plan

<BIDDER>	<Bidder Name>			<Order No.>			
<Signature of quality control manager and date>							
LEGEND: H = Hold Point - Operation or procedure must be witnessed by purchaser's representative before moving component to next operation. W = Witness Point - Operation or procedure may be witnessed by purchaser's representative if representative is present during manufacture. D = Document Required - Quality assurance must provide certified copy of inspection or test report to purchaser's representative.							
Procurement Spec No. <Spec No.> Rev. <Rev. No.> Activity	H	W	D	Proc. Spec. Clause	Bidder Spec. No.	Bidder Clause No.	Bidder Form No.
Gear raw material	X		X				
Process	X		X				
Form	X		X				
Chemistry	X		X				
Grain size	X		X				
Hardenability	X		X				
Cleanliness	X		X				
UT inspect forgings	X		X				
Inspection of gear teeth	X		X				
Basic geometry		X	X				
Accuracy	X		X				
Root fillets		X	X				
Grinding stock removal		X	X				
Surface roughness	X		X				
Magnetic particle	X		X				
Surface temper	X		X				
Surface hardness	X		X				
Inspection frequency	X		X				
Inspection of coupons	X		X				
General	X		X				
Case hardness	X		X				
Case depth	X		X				
Core hardness	X		X				
Case microstructure	X		X				
Carbides	X		X				
Decarburization	X		X				
Carbon content	X		X				
Microcracks	X		X				
Secondary transform. products	X		X				
Intergranular oxidation	X		X				
Retained austenite	X		X				
Core microstructure		X	X				
Post carburize cold treat		X	X				
Housing accuracy		X	X				

(continued)

Table C.1 *(concluded)*

Shaft material		X	X				
Shaft hardness		X	X				
Shaft accuracy		X	X				
Shaft magnetic particle		X	X				
Gearbox assembly	X		X				
Tests	X		X				
Contact patterns	X		X				
Load or no-load tests	X		X				
Dykem	X		X				
Lubrication	X		X				
Sound level	X		X				
Vibration level	X		X				
Oil leaks	X		X				
Oil sump temperature	X		X				
Dykem patterns	X		X				
Corrective action	X		X				
Documentation	X		X				
Preparation for shipment	X		X				
NOTE: This is a sample plan and is not inclusive of all items; the important items are shown.							

A report summarizing the design audit should be prepared. Manufacturing should not begin until the purchaser approves the engineering drawings and QA plan, and all agreed to design changes are incorporated into the procurement specification.

C.3.6 Review and approve engineering drawings

The engineering drawings should be reviewed to confirm they meet the requirements of the procurement specification.

C.3.7 Review and approve QA plan

The final QA plan should be reviewed to confirm it meets the requirements of the procurement specification for manufacturing, quality assurance, and testing. The detailed quality assurance plan for the proposed gearbox should be consistent with the manufacturer's overall quality system, such as ISO 9000 or an equivalent. If the gearbox manufacturer wishes to deviate from the procurement specification or QA plan, the alternatives should be described by the following:

- reference to procurement specification clause;
- description of alternative;
- requirements for verification of alternative;
- purchaser's signature of approval.

Table C.1 is a sample QA plan for the prototype gearbox, first article gearboxes, and production gearboxes. It emphasizes gears but includes other items. A similar plan is needed for each load bearing component and the gearbox as an assembly. The QA plan should be detailed enough to uncover any problems during manufacturing of prototype gearboxes. The same QA plan, except as modified based on results of the prototype test, should be used for first article gearboxes to ensure corrective actions have been successful, and the gearboxes meet requirements of the procurement specification before production manufacturing begins. The same QA plan should be used for production gearboxes. However, the frequency of inspections and tests, and schedule of hold and witness points should be negotiated between the purchaser and gearbox manufacturer.

As a minimum, the QA plan should specify control methods for the following:

- gear raw material;
- quality control of subcontracted work and purchased parts;
- quality control of gear metallurgy;
- inspection of gear teeth;
- housing accuracy;

- shaft accuracy;
- quality control in assembly including fitting, cleanliness, serialization and traceability of components;
- gearbox tests, acceptance criteria, and record keeping requirements.

Documentation required by the QA plan should be traceable. All gears and shafts should be serialized and all inspection documents should record serial numbers of components. Serial numbers of all gears and shafts should be traceable from the serial number on the gearbox nameplate and traceable to raw material heat and melt numbers. All test specimens, representative test coupons, heat treatment records, and all significant documents from manufacturing, inspection, testing, and processing should be traceable to components they represent. All measuring instruments and artifacts should be traceably calibrated to national standards and have current calibration certificates. All QA documents generated by the gearbox manufacturer should be maintained for a period agreed to by the purchaser and the gearbox manufacturer, but not less than ten years.

C.3.8 Review and approve manufacturing schedule

The manufacturing schedule should allow sufficient time for corrective action deemed necessary from results of the prototype test, and changes to manufacturing or the QA plan deemed necessary based on inspections of first article gearboxes.

C.3.9 Evaluate performance of prototype gearbox

After the prototype gearbox has been tested and inspected, and all necessary changes to design, manufacturing, and QA plan are made, manufacture of first article gearboxes should be approved.

C.3.10 Inspect first article gearboxes

After the first article gearboxes are inspected, and supporting documentation reviewed, make recommendations for changes to engineering and manufacturing specifications and the QA plan.

C.3.11 Approve manufacture of production gearboxes

After the final engineering and manufacturing specifications and final QA plan have been approved, and first article gearboxes have met requirements of the final QA plan, manufacturing of production gearboxes should be approved.

C.3.12 Audit manufacturing and testing of production gearboxes

Periodic audits of manufacturing and testing should be conducted to resolve problems and ensure compliance with the procurement specification and QA plan.

C.3.13 Audit installation, startup, and operation of production gearboxes

Installation, startup, and operation should be audited to ensure all instructions for installation, operation, and maintenance are properly implemented. Gearbox performance should be closely monitored during startup and the first few weeks after startup, followed by periodic monitoring during operation. Monitoring should include measurements of temperature, sound, and vibration, and lubricant analyses.

C.5 Resolution process

A formal process to allow for resolution of as-built deviations from the manufacturing specifications should be developed. The method to resolve deviations should be agreed to between the purchaser and the gearbox manufacturer as part of the QA plan. For example, the resolution process could be utilized if a grinding notch in a gear tooth occurs.

(This page is intentionally blank)

Annex D
(informative)
Operation and maintenance

[The foreword, footnotes and annexes, if any, are provided for informational purposes only and should not be construed as a part of ANSI/AGMA/AWEA 6006-A03, *Standard for Design and Specification of Gearboxes for Wind Turbines.*]

D. Purpose

The operation and maintenance of a wind turbine gearbox is as important as designing, manufacturing and procuring the gearbox, and it should be fully defined prior to purchasing the gearbox. Startup, operating, and maintenance plans and procedures should be established by the gearbox manufacturer, lubricant manufacturer, and purchaser before the gearbox is placed in service.

D.1 Startup and run-in procedures

The bedplate, mounting surfaces, shims and shaft couplings must be accurately aligned for proper overall performance.

For maximum bearing and coupling life, shaft misalignment should be minimized. Load variations and temperature changes cause the alignment to change. Therefore, it is best to carefully align couplings to ensure that the couplings have adequate capacity to accommodate increases in misalignment. In some cases it is necessary to bias the cold alignment to minimize shaft misalignment at the operating temperature. For shaft mounted gearboxes, the torque arm should be properly located and mounted without excessive clearance in the mounting points to ensure that the gearbox housing is not twisted, and the high speed coupling is not misaligned. Before starting the equipment, these checks should be made:

- oil level and type;
- pipe connections;
- electrical connections;
- torque on mounting and gearbox bolts;
- operation of automatic shutdowns and alarms;
- coupling installation and alignment;
- inspection cover installation;
- heater, cooler, and fan operation.

During initial startup, these procedures are helpful:

- Pre-oil the unit to lubricate gears and bearings;
- For cold environment startups, preheat the lubricant. Load should not be applied until the oil has attained operating temperature;
- Start the gearbox slowly under light load. Check for proper rotation direction. Check system oil pressure;
- After oil circulates, stop the unit, check oil level, and add as necessary;
- Monitor the gearbox for vibration and temperature. If any problems are detected, shut down immediately, and take corrective action;
- If a factory run-in procedure is not performed, operate the first 10 hours at reduced load to run-in tooth surfaces. This will reduce the risk of scuffing and prolong the life of the drive. Not performing such a run-in may lead to premature failure;
- After a field performed run-in, the gearbox should be drained and flushed to remove contaminants, refilled with recommended lubricant and a new oil filter should be installed if applicable;
- Check coupling alignments and re-torque all bolts. Check all piping connections and tighten as necessary.

Finally, to confirm that the requirements of the procurement specification have been met, gearbox performance should be monitored under actual service conditions. Because the first few weeks after startup are critical, data on load, vibration, and performance should be collected. Not every application warrants full telemetry and strain gaging. However, power, temperature and vibration level should be recorded for every gearbox. Also the lubricant should be analyzed for contamination. These actions will check the purchasing process and involve the gearbox manufacturer in corrections as necessary.